Noble Elements Summary

Conveners: Jonathan Asaadi, Jen Raaf

March 22, 2021

CPAD 2021

Excellent presentations in our parallel sessions!

Thursday

A Digital Tension Measurement Device for Multi-Wire Particle Detectors	*Shion Kubota*	
Stony Brook, NY		11:00 - 11:20
Measuring trace krypton for the LUX-ZEPLIN dark matter search	*John Silk*	
Stony Brook, NY		11:20 - 11:40
Modeling Impurity Concentrations in Liquid Argon Detectors	*Yichen Li et al.*	
Stony Brook, NY		11:40 - 12:00
Purity monitoring for ProtoDUNE-SP	*Wenjie Wu*	
Stony Brook, NY		12:00 - 12:20
Low-energy Monoenergetic Neutron Production with a DD-Neutron Source for sub-keV Nuclear Recoil Calibrations in the LUX and LZ Experiments	*Will Taylor*	

Scintillation and Optical Properties of the Low-Background Scintillator, PEN	*Mrs Brennan Hackett*	
Stony Brook, NY		13:00 - 13:20
Wavelength-Shifting Performance of Polyethylene Naphthalate Films in a Liquid Argon Environment	*Ryan Dorrill*	
Stony Brook, NY		13:20 - 13:40
Light production in liquid and gaseous argon	*Dr Carlos Ourivio Escobar*	
Stony Brook, NY		13:40 - 14:00
Improving the Proportional Scintillation Signal of Liquid Argon by Xenon Doping	*Ethan Bernard*	
Stony Brook, NY		14:00 - 14:20
Modeling xenon and argon physics with the Noble Element Simulation Technique (NEST)	*Vetri Velan*	
Stony Brook, NY		14:20 - 14:40
Building low background kton-scale liquid argon time projection chambers for physics discovery	*Christopher Jackson*	
Stony Brook, NY		14:40 - 15:00

Friday

Augmented Signal Processing in Liquid Argon Time Projection Chambers with a Deep Neural Network	*Haiwang Yu*	
Stony Brook, NY		11:00 - 11:20
Using Photo-converting Dopants to Improve Large LArTPC Performance	*Joseph Zennamo*	
Stony Brook, NY		11:20 - 11:40
QPIX, a novel pixel technology for very large noble element detectors	*Austin McDonald*	
Stony Brook, NY		11:40 - 12:00
High pressure gas TPC technology for neutrinoless double beta decay searches: The NEXT program	*Jonathan Haefner*	
Stony Brook, NY		12:00 - 12:20
Metastable Liquids: Breakthrough Technologies for Dark Matter and Neutrinos	*Prof. Matthew Szydagis*	
Stony Brook, NY		12:20 - 12:40

Designing and building a pair of scintillating bubble chambers for WIMPs and reactor CEvNS	*Rocco Coppejans*	
Stony Brook, NY		13:00 - 13:25
HeRALD - light dark matter search with superfluid Helium-4	*Junsong Lin*	
Stony Brook, NY		13:25 - 13:50

2019 DOE Basic Research Needs Study

Noble Elements Priority Research Directions

Priority Research Direction (PRD)	Technical Requirement (TR)
PRD 4: Enhance and combine existing modalities to increase signal-to-noise and reconstruction fidelity PRD 5: Develop new modalities for signal detection	TR 1.3.3, 2.1, 2.4, 2.5, 2.7, 2.9, 3.3, 3.6, 3.9, 3.12, 3.13, 3.15, 3.17, 3.19
PRD 6: Improve the understanding of detector microphysics and characterization to increase signal-to-noise and reconstruction fidelity	TR 2.8, 2.9, 3.3, 3.6, 3.9, 3.12, 3.13, 3.15, 3.17, 3.19
PRD 25: Advance material purification and assay methods to increase sensitivity	TR 2.3, 3.1, 3.4, 3.7, 3.10
PRD 26: Addressing challenges in scaling technologies	TR 2.1, 2.3, 2.4, 2.7, 2.9, 3.2, 3.5, 3.8, 3.11 , 3.14, 3.16, 3.18, 3.20

Table 15: Table mapping Priority Research Directions to Technical Requirements.

PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

J. Zennamo

Photon Conversion

- These chemicals work by having an ionization energy near the scintillation photon energy
  - Convert scintillation light into ionization charge
- Literature has explored many potential choices (*), the most commonly used:
  - Tetramethylgermane (**TMG**), $(CH_3)_4Ge$
  - Trimethylamine (**TMA**), $N(CH_3)_3$
  - Triethylamine (**TEA**), $N(CH_2CH_3)_3$

Scintillation γ Energy

LAr	9.6 eV
LAr+Xe	7.0-9.6 eV

Ionization Energies

TMG	9.2 eV
TMA	7.8 eV
TEA	7.5 eV

(In LAr these drop by ~0.7 eV)

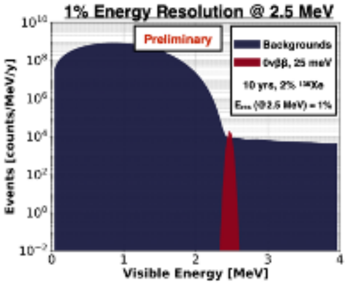
- **These chemicals have a long track record of demonstrations in the literature starting back in the early 1970s**

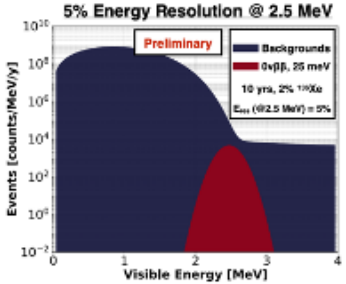
(*) D.F. Anderson, Nucl. Instr. and Meth. A 242 (1986) 256

J. Zennamo, Fermilab 9

Other Benefits of Xenon-Doping

- On top of modifying the detector's performance ^{136}Xe is also a 0νββ candidate isotope
  - Doping with ^{136}Xe could enable a 100-ton scale search for 0νββ
- **Concept:** Dope DUNE FD module LAr with 2% ^{136}Xe ($Q_{\beta\beta}$ = 2.5 MeV)
  - Enabling a **>300-ton** mass of xenon to sit within a 2 m fully active LAr buffer, eliminating most surface backgrounds
  - Additional background suppression comes via multisite tagging
- **To enable such a search one needs to utilize ^{42}Ar depleted LAr**





J. Zennamo, Fermilab

Publication pending, A. Mastbaum, F. Psihas, J.Zennamo

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PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

E. Bernard

S2 Light Measurement Improvement by Addition of Xenon To Argon

Improvements in light production and sensing of the S2 pulse

- Xe – containing excimers emit at longer wavelengths that are more efficiently measured.
- Xe – containing excimers emit their light faster, shortening pulse duration.
- Xe* has a lower threshold for excitation → more excitations per drift electron

Improvements in ionization yield of the liquid (speculative)

- Xenon has a lower ionization energy that argon → more electrons per unit deposited energy
- Xenon may be ionized by the Penning process $Ar^* + Xe \rightarrow Ar + Xe^+ + e^-$

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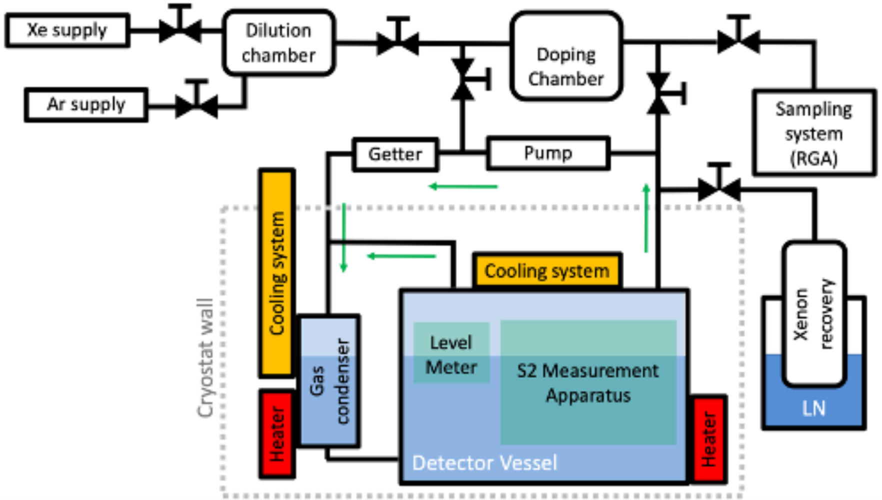
Xenon-Doped Argon Circulation Scheme



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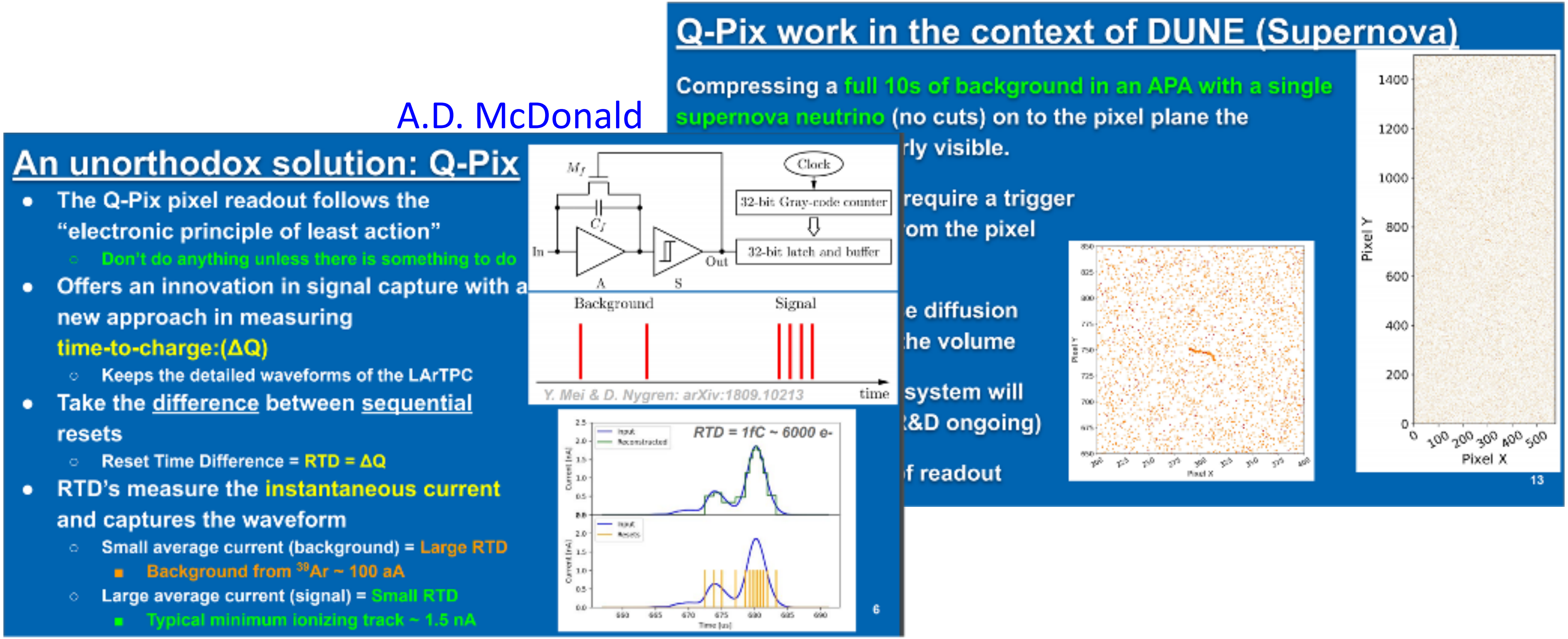
PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

A.D. McDonald

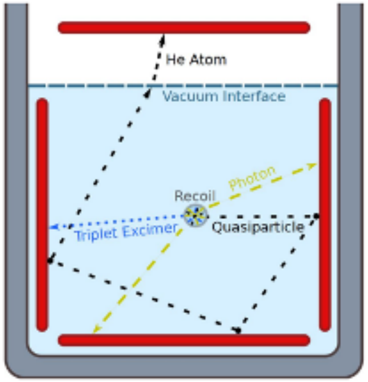


PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

J. Lin

HeRALD concept and sensitivity paper
PhysRevD.100.092007

Helium **R**oton **A**pparatus for **L**ight **D**ark matter (HeRALD)



- Operated at mK
- Calorimeters with TES readout
  - submerged in liquid
    - Detect **UV photons**, **triplet molecules** and **IR photons**
  - suspended in vacuum
    - Detect UV photons, IR photons and **He atoms** (evaporated from quasiparticle)

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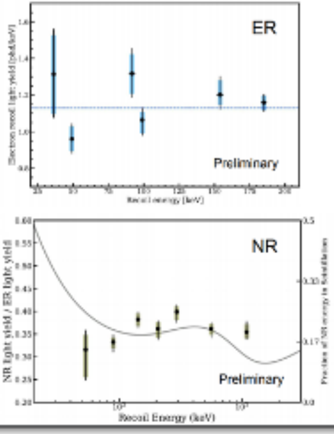
Light yield measurement of superfluid He-4



- First measurement in tens of keV
- ER yield relatively flat (as expected)
- NR yield agrees pre-defined model
- Working on lower energy (~ keV)
  - ER: Compton scattering from Co-57 source
  - NR: SbBe with iron filter

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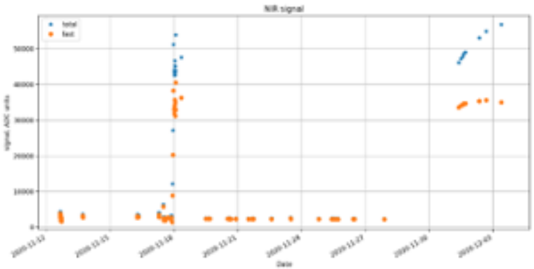
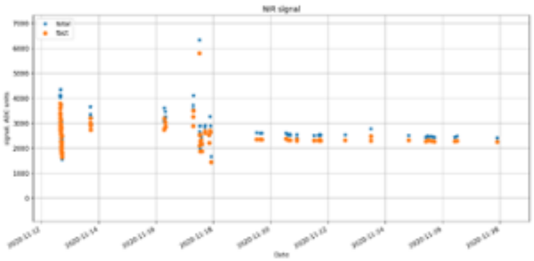
PRD 5: Develop new modalities for signal detection

C. Escobar

Fermilab

NIR Observed Signals





Clean liquid phase:

- SiPM bias voltage variation
- Significant reduction of the observed signal on Nov 17 ~ noon

Gas 1 phase:

- Major increase of the observed signal
- Emergence of a slow component

Dirty liquid phase:

- Observed signal comparable to the end of clean liquid phase

Gas 2 phase:

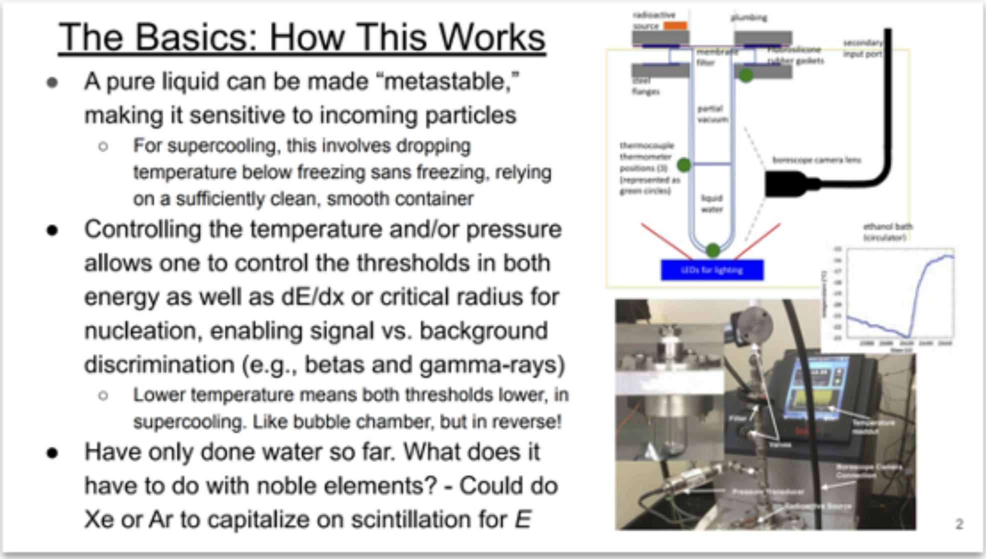
- Fast component comparable with the Gas 1, ~ steady
- Increase of the total/ slow component

PRD 5: Develop new modalities for signal detection

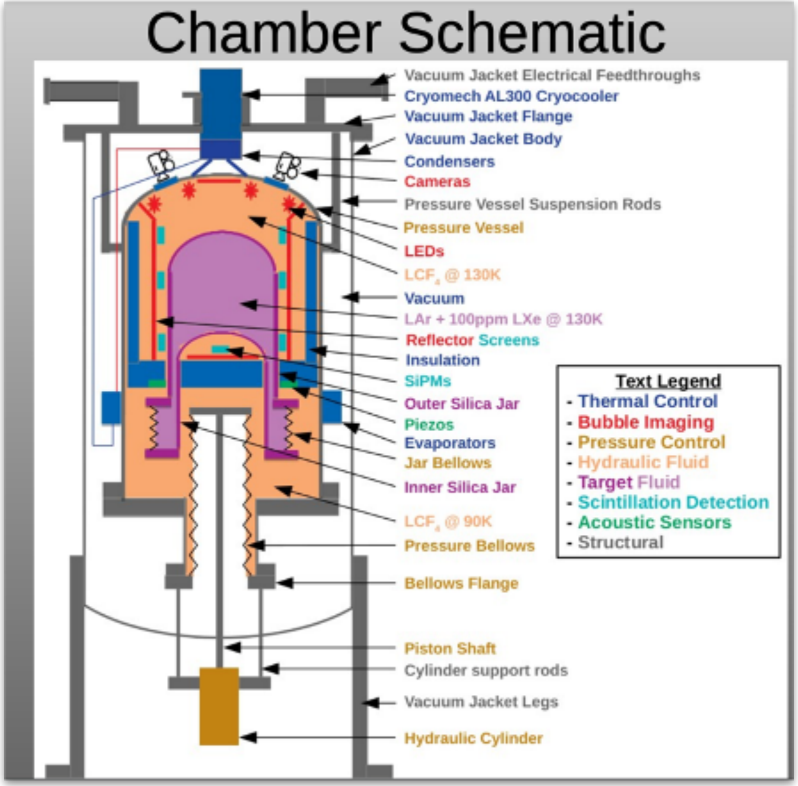
Metastable liquids: phase transition detectors

- Snowball Chamber (super-cooled water)
- Scintillating Bubble Chamber (super-heated LAr-LXe)

M. Szydagis

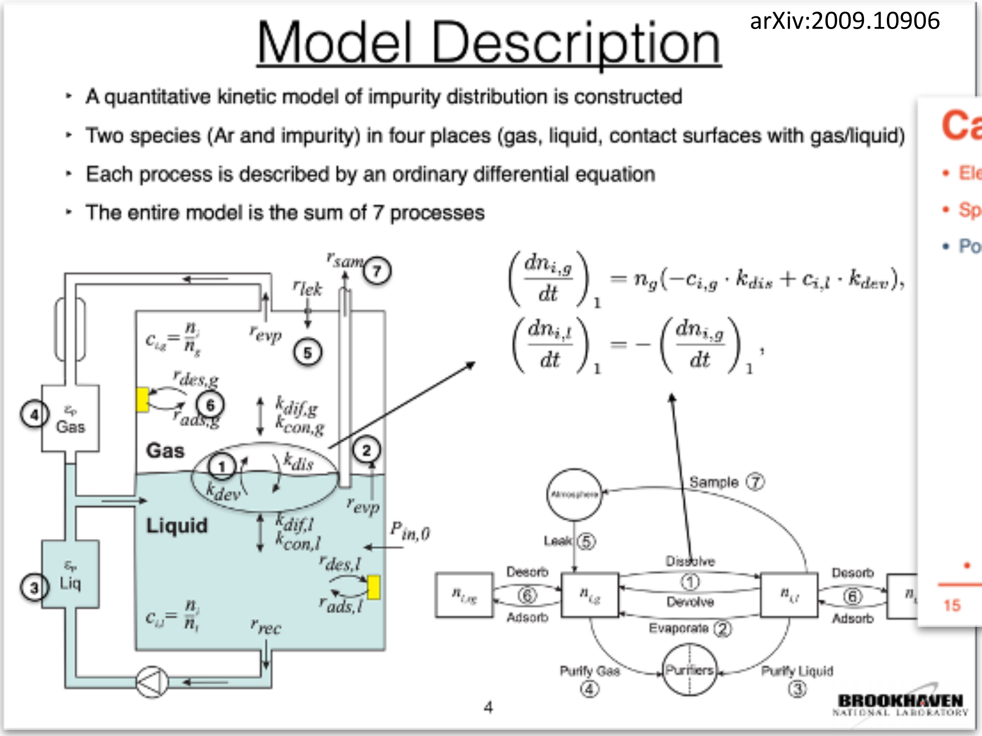


R. Coppejans

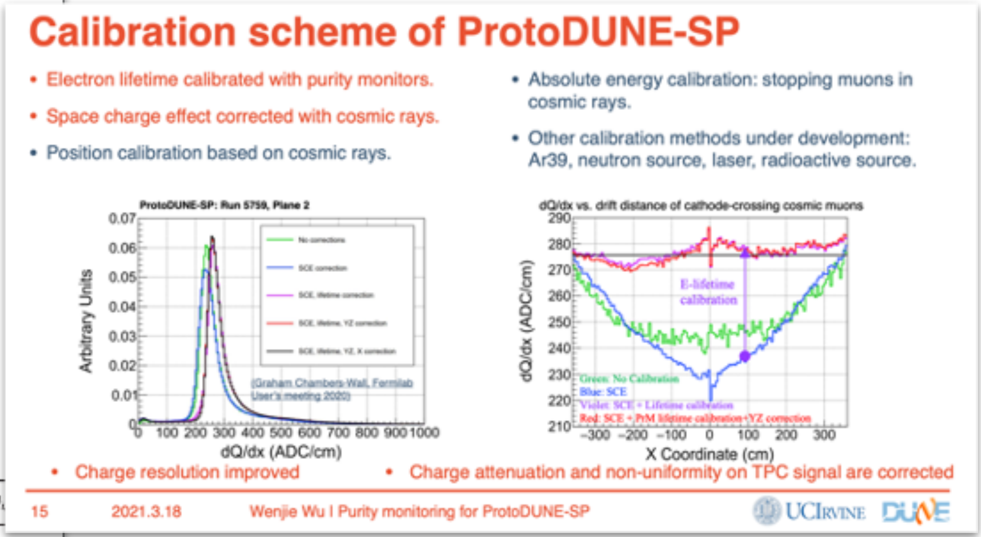


PRD 6: Improve the understanding of detector microphysics and characterization to increase S:N and reconstruction fidelity

Y. Li

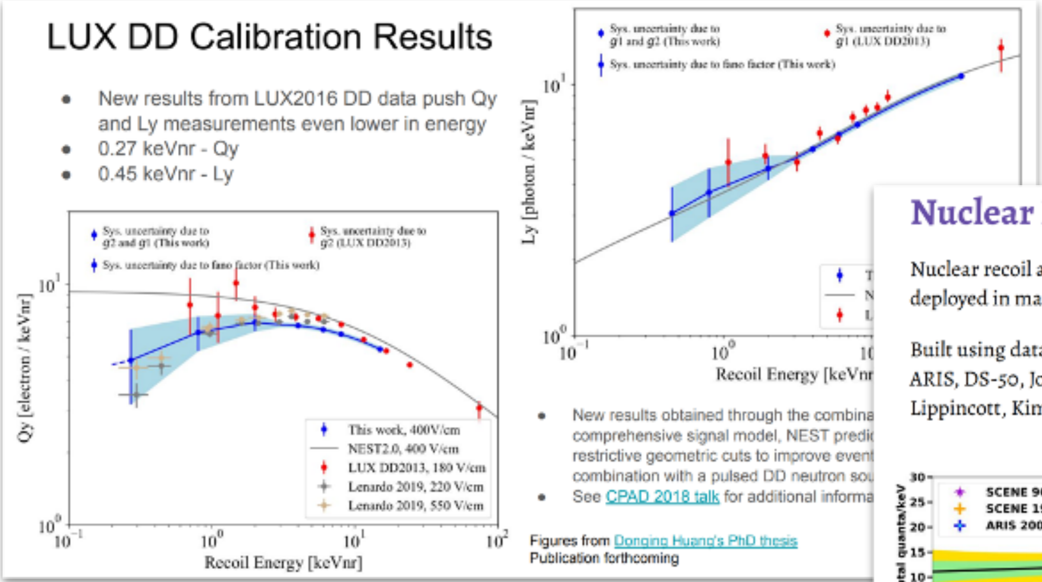


W. Wu

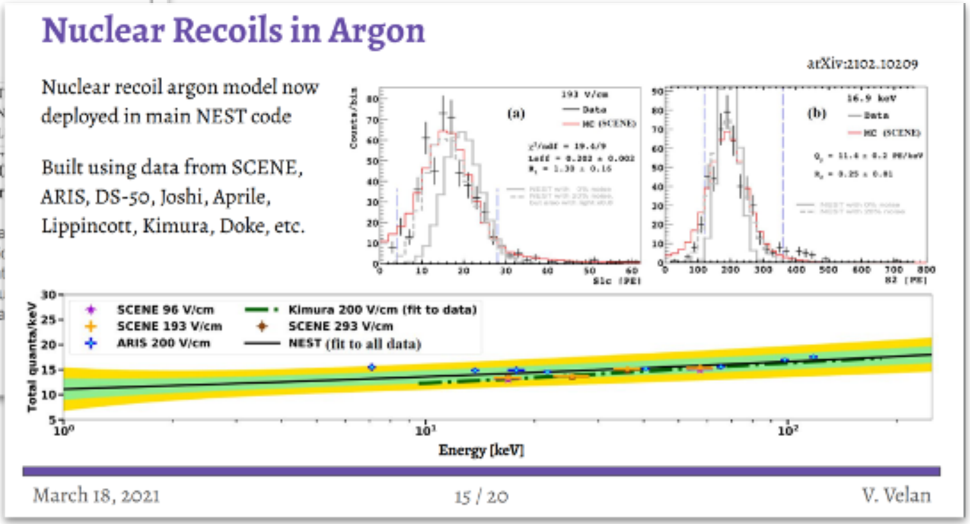


PRD 6: Improve the understanding of detector microphysics and characterization to increase S:N and reconstruction fidelity

W. Taylor

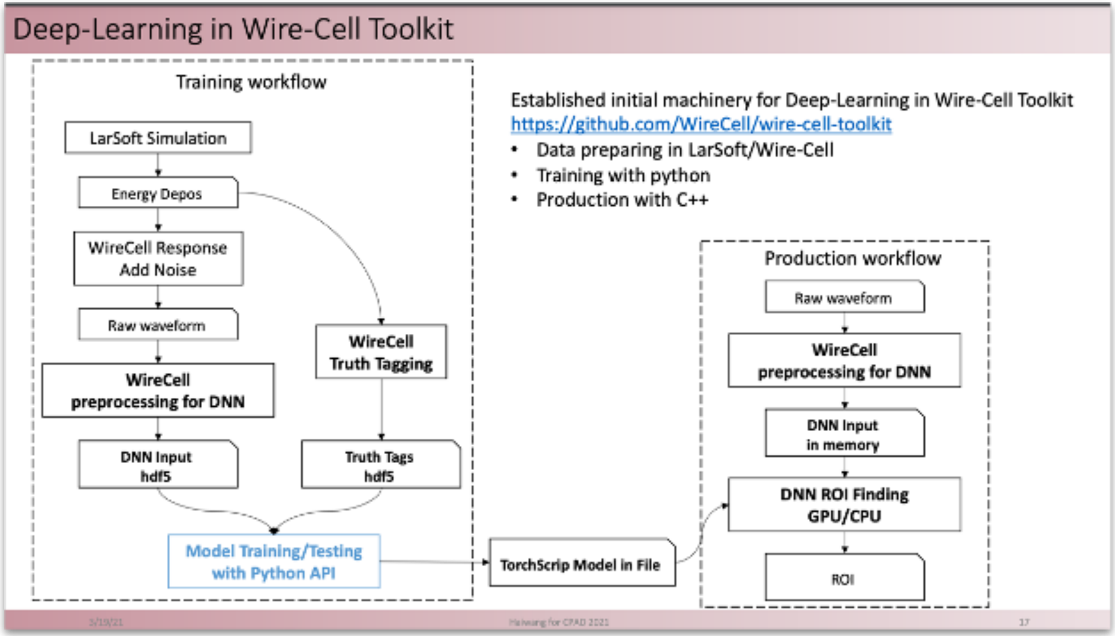


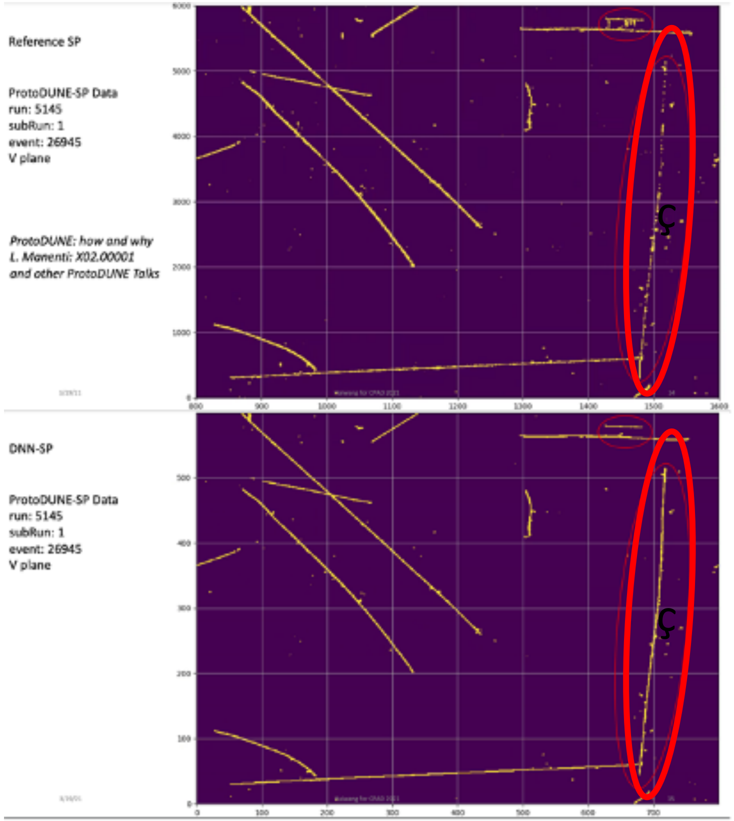
V. Velan



PRD 6: Improve the understanding of detector microphysics and characterization to increase S:N and reconstruction fidelity

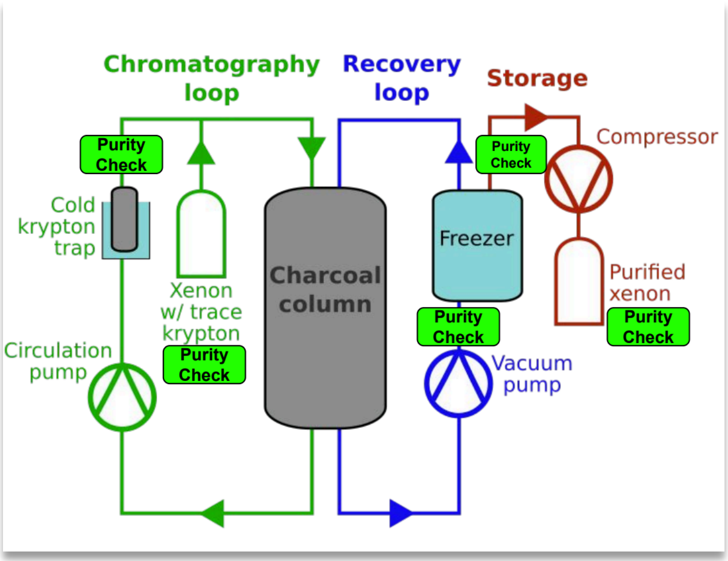
H. Yu



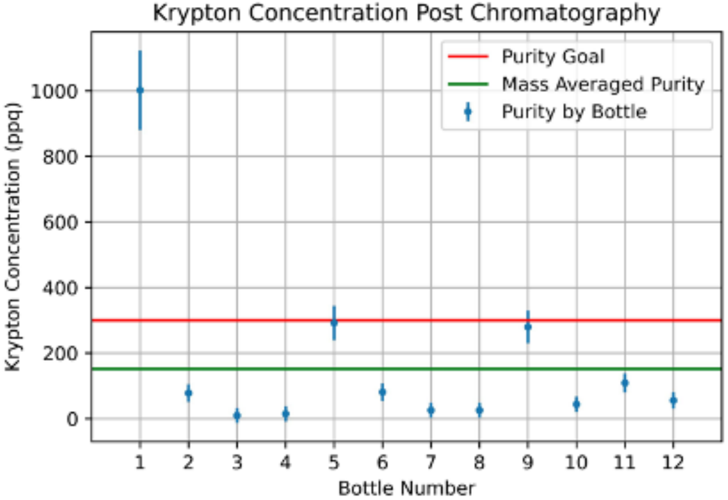


PRD 25: Advance material purification and assay methods to increase sensitivity

J. Silk



De-Kryptonated Xenon



Cleaned xenon is put into storage pack of 12 bottles

Result above is ~970 kg, with a total mass averaged purity of 152 ppq ^{nat}Kr g/g, satisfying the 300 ppq purity goal

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PRD 25: Advance material purification and assay methods to increase sensitivity

B. Hackett

Conclusion

- PEN is a novel scintillating material
- It has potential applications in both noble detectors and low background experiments
- PEN has a demonstrated structural stability
  - Yield strength higher than copper at cryogenic temperatures
- Injection molding can prevent crystalline structures forming in PEN
  - Improved optical clarity
  - Alternative geometries other than commercially available films

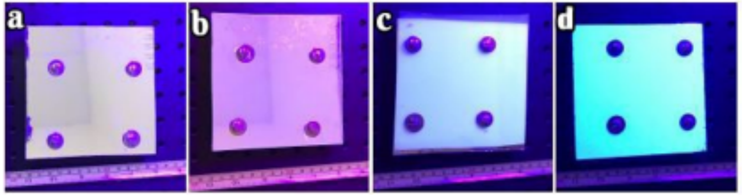
15 OAK RIDGE National Laboratory | THE UNIVERSITY OF TENNESSEE KNOXVILLE

R. Dorrill

ILLINOIS INSTITUTE OF TECHNOLOGY

Samples Tested

Data Sample	Origin	Trade Name	Thickness	Properties
PEN01	Piedmont	Teonex Q65FA	0.125m	Ultra-clear
PEN02	ORNL	Teonex TN-8065S	1.5mm	Low crystallinity, clear
PEN03	Millipore Sigma	Teonex Q53	0.125mm	Biaxially oriented, hazy
PEN04	Goodfellow	Teonex Q53	0.125mm	Biaxially oriented, hazy
TPB	Manchester Univ.	-	0.003mm	Evaporatively deposited
Bare	-	-	-	No WLS layer applied



The bare reflector (a), PEN01 (b), PEN04(c), and TPB (d). Note PEN04's hazy appearance compared to PEN01.

Alternative WLS materials with low radioactivity

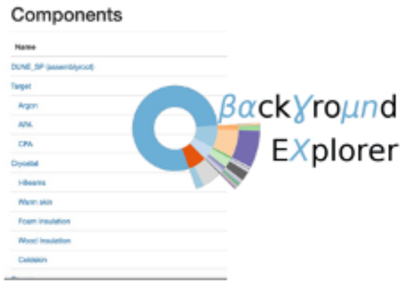
Also relevant for PRD #4!

PRD 25: Advance material purification and assay methods to increase sensitivity

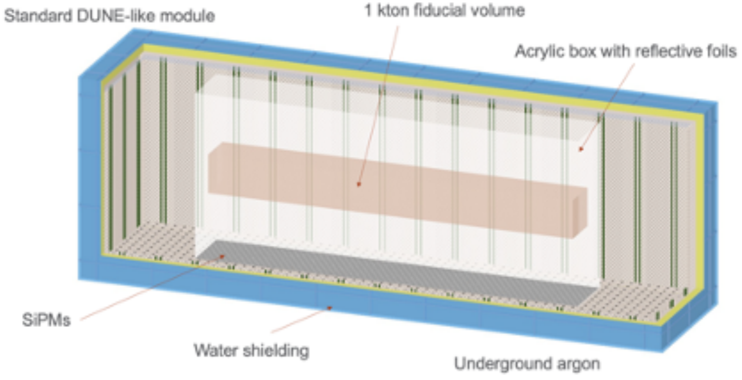
C. Jackson

How to build this?

- Assay management
  - Radiopurity.org based assay manager
    - ✓ Interface for non-experts to request assays
    - ✓ Guided input of relevant information
    - ✓ Low background experts guide distribution of assay work
    - ✓ Tracks samples and locations
- Assay results and triage
  - Background Explorer
    - ✓ Toolkit for modeling radioactive backgrounds
    - ✓ Rapid evaluation of effect of new assay measurement on background tables
    - ✓ Originally developed for SuperCDMS by Ben Loer
    - ✓ https://github.com/bloer/bgexplorer-demo



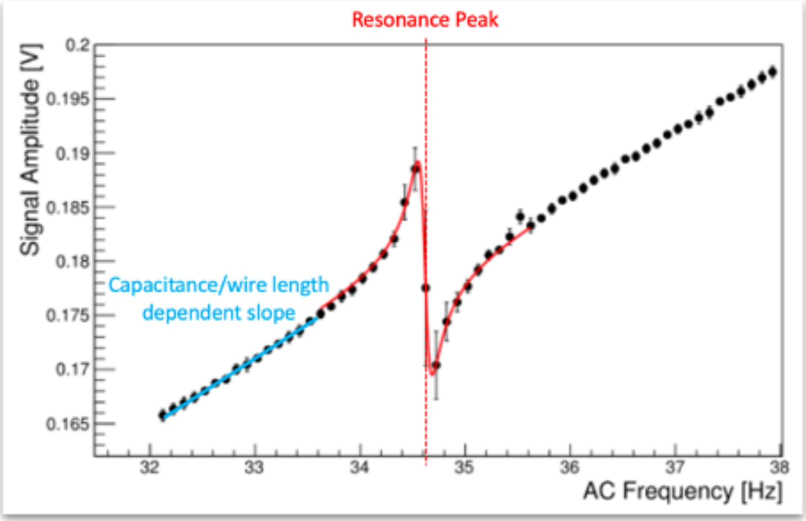
Low Background Module

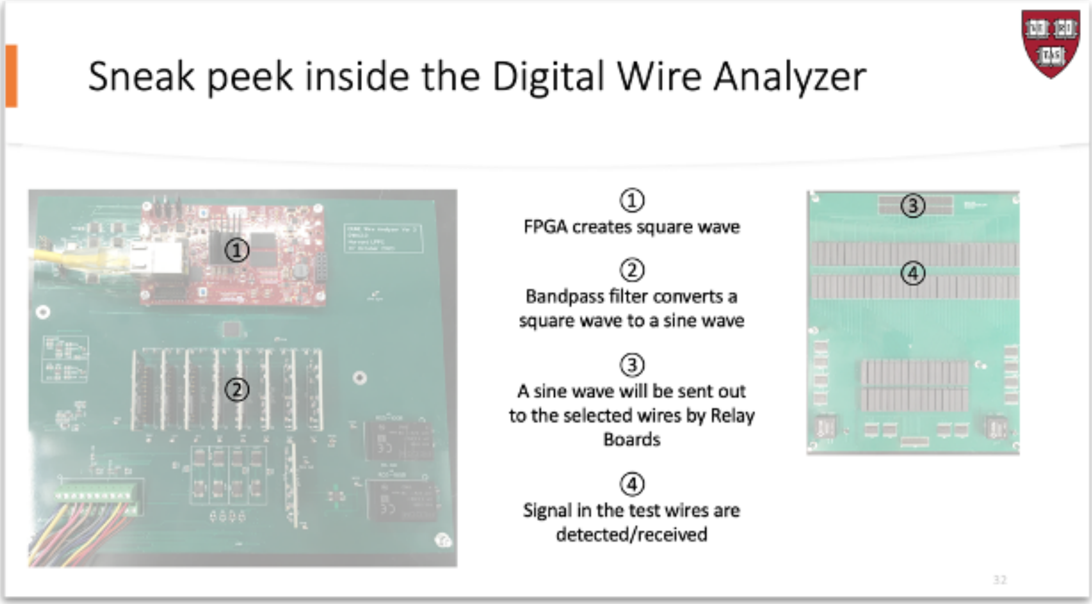


PRD 26: Addressing challenges in scaling technologies

New techniques for measuring wire tensions in future large TPCs...

S. Kubota





A Novel Electrical Method to Measure Wire Tensions for Time Projection Chambers
Nucl.Instrum.Meth.A 915 (2019) 75-81

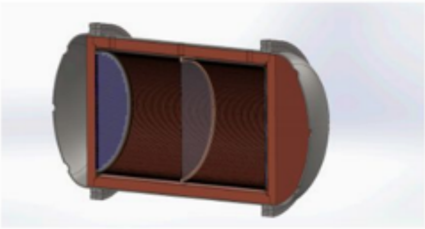
PRD 26: Addressing challenges in scaling technologies

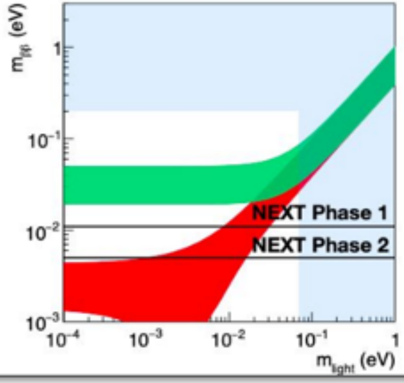
R&D to enable to ton-scale 0nuBB

J. Haefner

NEXT-Ton: basics

- Require a larger detector (10x mass of N100)
- With larger size, some challenges:
  - Larger volume to calibrate
  - Longer drift distance
- Must maintain:
  - excellent resolution
  - topological rejection power





Two approaches developed in parallel:

- Phase 1, High Definition: incremental approach, using/improving existing technology.
- Phase 2, Barium Tagging: based on disruptive new concept (SMFI Ba++ tagging).

Phased approach

- ~1 ton of 136Xe introduced per phase.
- Ultra pure materials. SiPMs as the only sensor.

Phase 1:

- Improves topological signature, improves energy resolution
- Reduces radioactive budget (no PMTs)
- Energy plane made of large area SiPMs (design similar to that of Dark Side)
- Potential to reduce SiPM dark count by cooling detector
- 2.6×10^{-6} cts / keV·kg·year total background rate

Phase 2:

- Tracking and energy measured in anode.
- Cathode implements Barium Tagging System
- Virtually background free

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Closing Remarks

- ❑ Lots of interesting results and advances in techniques, tools, and instrumentation
- ❑ Focus: how to do things at larger scale with higher sensitivity
- ❑ Looking forward to see how much farther we will be able to advance by the next CPAD!

Thank you to all the session speakers for their excellent talks!